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Strain measurement under the minimal controller synthesis algorithm and an extensometer design

*S. Bulut**

Cumhuriyet University, Mechanical Engineering Department, 58140 Sivas, Turkey

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ABSTRACT

In this paper, minimal controller synthesis (MCS) algorithm is used in the case of strain measurement for the first time. The MCS control is an adaptive control method and it can be recommended as a robust controller for the servohydraulic materials testing machine. The algorithm coped with various specimens, which have different materials and diameters. The control accuracy is important in materials testing due to the fact that even smaller overshoots or undershoots can cause undesirable results in cyclic loading. For this reason, the controller parameters needs to adjusted according to the changes in the plant parameters for acceptable plant output responses.

In order to measure strain signal a simple LVDT extensometer was designed. In this set tests, two different specimens were used: aluminium alloy specimens of diameter 10 mm and EN24T steel specimens of diameter 7 mm. The MCS control was implemented in two degrees of freedom form and produced very satisfactory plant output responses owing to the fact that the results produced by the control are in the range of actual values. This indicates that the MCS control can be used in strain measurement very effectively. It may also indicate the possibility of using the MCS control other materials testing applications like strain control and temperature cycle tests.

1. Introduction

Adaptive control techniques are often used for a plant with unknown and time varying dynamics. Especially a model reference adaptive control (MRAC) technique can make the plant output coincide with a reference output. Since electrohydraulic servo systems are often used under varying conditions, the application of this technique to a servohydraulic materials testing machine is expected to be very powerful and useful as studied (Edge and Figuerodo, 1987).

The main purpose of this paper is to present the results of the first known implementation of the minimal controller synthesis (MCS) algorithm in the case of strain measurement. The MCS algorithm was originally developed by Stoten and Benchoubane (1990a) as an extension to the model reference adaptive control (MRAC) algorithm of Landau (1979). The algorithm has a simple structure with relatively few computational requirements per time step. MCS requires no prior knowledge of the plant parameters for implementation, and yet is guaranteed to provide global asymptotic stability of the closed-loop system, unlike linear controller strategies. Additionally, the designer is not require to synthesize the MCS controller gains, since this done automatically by the algorithm, given arbitrary (often zero) initial conditions (Stoten and Benchoubane, 1990b). The MCS control has been shown to be robust in the presence of unknown external disturbances and unmodelled dynamics in the plant. The algorithm has been shown to be effective in a number of areas and it

* Tel.: +90 346 2191010 1698.
E-mail address: sbulut@cumhuriyet.edu.tr.
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Nomenclature

$\mathbf{A}$	$(n\times n)$ nominal plant parameter matrix
$\mathbf{A}_m$	$(h\times h)$ reference model matrix
A_p	cross-sectional area of the specimen
$\mathbf{A}_r$	$(h\times h)$ reduced order plant parameter matrix
$\mathbf{B}_m$	$(h\times 1)$ reference model matrix
$\mathbf{B}_r$	$(h\times 1)$ reduced order plant parameter matrix
$\mathbf{C}_e$	output error matrix
$\boldsymbol{d}(\boldsymbol{x}_r,t)$	$(h\times 1)$ disturbance vector
D	diameter of the specimen
$e(s)$	tracking error
E	the modulus of elasticity
G_p	plant transfer function (scalar)
h	reduced order plant state dimension, $h<n$
k	instant of discrete-time integer (integer)
$\mathbf{K}$	MCS state feedback gain; (typically $\mathbf{K}(0)=0$)
$\mathbf{K}_r$	MCS forward loop gain; (typically $\mathbf{K}_r(0)=0$)
L	unloaded length of the specimen
n	nominal plant state dimension
$\mathbf{P}$	$(h\times h)$ symmetric positive definite matrix solution of the Lyapunov function equation
P_a	applied load on the specimen
$\mathbf{Q}$	$(h\times h)$ symmetric positive definite matrix associated with the Lyapunov equation
$\boldsymbol{r}(s)$	reference vector
s	Laplace variable
t	time
t_s	settling time
$\boldsymbol{u}(s)$	control signal
$\mathbf{x}$	$(n\times 1)$ plant state vector
$\mathbf{x}_e$	$(h\times 1)$ state error vector
$\mathbf{x}_m$	$(h\times 1)$ reference model state vector
$\mathbf{x}_r$	$(h\times 1)$ the reduced order plant state vector
$\mathbf{y}(s)$	plant output signal
$\mathbf{y}_e(s)$	output error signal

Greek symbols

α	MCS integral adaption gain (scalar), $\alpha>0$
β	MCS proportional adaption gain (scalar), $\beta\geq 0$
δ	elongation of the specimen
Δ	sampling interval
ε	strain
σ	longitudinal stress
τ	time
Ω	$=\beta-\alpha\Delta$

was applied to a large class of servohydraulic, pneumatic, electro mechanical systems and it was produced satisfactory plant output responses in work by Stoten (1990), Bulut (2000), and Stoten and Hodgson (1991). The algorithm was implemented to electrohydraulic servo systems in a simplified reduced order form in work by Bulut (2000), Stoten (1992) and Stoten and Bulut (1994) and produced satisfactory responses.

It is very necessary to know the localized stress–strain history of aircraft components subjected to complex multiaxial stress conditions. However, a detailed finite element analysis is often very time consuming. Consequently, a simple new method developed in work by Knop et al. (2000) which combines modern constitutive theory with either Neuber's, or Glinka's, approach to calculate the localized notch strains. Peters and Heymsfield (2003) examined the use of meshes consisting of constant elements created from polygons having differing numbers of element nodes.

New extensometers were developed which needs no attachment of line markers or mechanical tracers on a specimen in work by Yamaguchi et al. (2006). In this work, the displacement of the marker position was tracked by moving a head containing a laser diode, an imaging lens and an image sensor under the feedback control that compensates for the speckle displacement detected. In a similar manner, the local diametral strains of specimens in the tension Kolsky bar (or split Hopkinson pressure bar) experiment were measured using a laser occlusive radius detector (LORD) in work by Li and Ramesh (2007). In situ image capture together with processing technique adapted from particle image velocimetry were used by Abadi et al. (2007) in order to have more detail about the local strain fields. The Direct Measurements, Inc. Symbolic Strain Gage was used to measure the local plastic strains in work by Ranson et al. (2005). The gage technology was utilized the symbolic properties of a two-dimensional bar code (or compressed symbol) to make stress-analysis measurements.

Experimental results demonstrated that fiber Bragg grating (FBG) sensors could measure strain with higher resolution. Lou et al. (2002) described a proportional integrated control theory which was to control the filter FBG's Bragg wavelength. Mizutani et al. (2003) found that the small-diameter FBG could also detect transverse cracks in quasi-isotropic laminates quantitatively. FBG sensors were interrogated with the Pcbus eXtension for Instrumentation, a type of opto-electronic instrument and this advanced interrogated system was used to measure strains inside the metal or composite structures in work by Tsuda and Lee (2007). Shobu et al. (2007) measured the internal strain of a 5-mm thick austenitic stainless steel sample (JIS-SUS304L) by using high energy white X-rays from a synchrotron radiation source at SPring-8.

A multimodule strain measuring and data processing system equipped with microprocessors and 4096 channels were controlled by a single computer in work by Ser'eznov et al. (2004). In this work, in order to increase the general productivity of the system a Host controller was employed.

The plant dynamics changes enormously during materials testing due to the changes in specimens and the machine characteristics. However, closed-loop control accuracy is crucial in materials testing applications due to the fact that even smaller overshoots or undershoots can cause undesirable results therefore, controller tuning is also important in such tests. The suitable controller parameter values for any one test depend on the nature of the test, the specimen characteristics and the dynamics of the materials testing machine. Manual tuning of the controller parameters can be a serious problem especially many controller parameters need to be reset during the operation of the machine. Therefore, using adaptive controller in this field has many advantages, such as adaptivity to the changes in the working condition.